Economic Values of Crop Genetic Resources

Attaching a value to genetic resources is a complex task. Describing the kinds of benefits associated with these resources is easier. The simplest benefit arises from the direct use of genetic resources: to produce food and fiber or to help create new varieties of crops and livestock. These direct uses are the focus of this report, although option value may also be an important motivation for their conservation.[1]

The ultimate direct-use benefits of crop genetic resources are measured in the increased output, higher quality, better resistance to pests, diseases, and other stress, and other characteristics found in improved crop varieties. These benefits derive not only from the genetic resources contained in precursor wild relatives, but also from the efforts of farmers who domesticated the crop and developed landraces through many years of selection; the work of collectors and gene banks that assembled and preserved genetic material in the form of landraces and wild relatives; and the work of plant breeders who have continued to develop and improve crop varieties.

Estimating the Benefits of Genetic Enhancement

Separating the contributions of breeders from the contributions of the germplasm with which they work is difficult. Thus, many studies have focused on the value of "genetic enhancement," or the value arising from both genetic material and its use by breeders. Most efforts to measure genetic enhancement have focused on specific crop breeding programs, using one of two related methods. The first measures benefits derived from a breeding program directly, and calculates rates of return to plant breeding efforts by comparing breeding program expenditures with their benefits. Many rate-of-return studies depend on the second method, some form of growth accounting. Growth accounting attempts to account for all factors affecting yields and then estimates the portion of the yield increase due to genetic enhancements.[2]

Rate-of-return studies sometimes base their estimates of the benefits from genetic enhancement on experimental estimates of yield gains. Plant breeders and other crop scientists may measure genetic gains in crop yield by conducting experiments that attempt to control for the effects of other inputs.[3] Although these studies focus specifically on genetic gains in yield, they do not always correctly value the economic benefits derived from the use of genetic resources for two reasons. First, yield trials that estimate genetic gains in yield are often conducted with input levels that farmers would not use or under environmental conditions that farmers would not face, in part because such experiments rely on control of other inputs for statistical validity. But plausible farmer responses in the face of changing technologies and market-environmental conditions suggest that yield gains in the field are likely to differ from experimental yield gains (Alston et al., 1995). Second, the resulting supply shifts for individual farmers would need to be aggregated to an industry supply shift in order to analyze economic costs and benefits to all producers and consumers.

[1]Genetic resources may also have economic value even if they are not currently being used. By preserving resources, we retain the option to use them in the future, when they may become important for agricultural, pharmaceutical, ecological, or industrial applications—even if we do not currently know precisely what those resources or applications are (Kaplan, 1998). Even if they are never used, diverse genetic resources may be valued by some people simply for their existence, or as a bequest left intact to future generations (Barbier et al., 1995).

[2]Growth accounting is often indicative rather than exact. Various factors (such as improved germplasm and improved crop management practices) frequently interact with one another, making it difficult to isolate the contributions of a single source. Interaction also means that the productivity gain from simultaneous adoption often exceeds the sum of the productivity gains when new varieties or crop management practices are adopted separately (Morris and Heisey, 2003).

[3] See Duvick (1977, 1984, 1992) on maize (corn) in the U.S., and Feyerherm and Paulsen (1981); Feyerherm, Paulsen, and Sebaugh (1984); Schmidt (1984); Cox et al. (1988); and others listed by Heisey, Lantican, and Dubin (2002) on wheat in both industrialized and developing countries.

Studies valuing the plant breeding component of genetic enhancement (see box, "Economic Studies of the Value of Genetic Enhancement") consistently demonstrate its high utility in creating new varieties with higher yields and better resistance to disease. In most cases, too, the economic benefits of genetic enhancement far surpass the costs. These studies do differ in methodology, so the magnitude of estimated economic benefits is often not consistent across studies. Although Evenson and Gollin (1997) made some efforts to estimate the values of genetic resources directly, for the most part, valuation methodologies have not separated out the contribution made by plant breeding from the

Economic Studies of the Value of Genetic Enhancement

Thirtle (1985) estimated the contributions of biological advances—which include both genetic enhancements and other land-saving technological change—in U.S. crop production using growth accounting (controlling for changes in other inputs such as fertilizers, machinery, and pesticides). Thirtle estimated that biological advances increased corn yields an average of 1.7 percent per year between 1939 and 1978; wheat 1.5 percent; soybeans 1.1 percent; and cotton 0.5 percent. Thirtle further concluded that biological improvements contributed to 50 percent of the yield growth of corn, 85 percent for soybeans, 75 percent for wheat, and 24 percent for cotton. In Thirtle's definition, however, biological improvements included both the use of improved varieties and other land-saving changes in agronomic practices.[1]

Byerlee and Traxler (1995) estimated a rate of return of 52 percent for joint international/national wheat breeding programs in developing countries. Pardey et al. (1996) also used rates of return, focusing on the spillover economic benefits of breeding research—i.e., benefits that accrue in regions or countries other than those originally targeted. They analyzed benefits in the United States (either to U.S. research programs or directly to U.S. farmers) from plant breeding research conducted in 2 of the 15 International Agricultural Research Centers (IARCs) that make up the Consultative Group on International Agricultural Research (CGIAR) system. Pardey et al. estimated returns on U.S. financial support to these two programs and found benefit-cost ratios for the United States of up to 48 to 1 for rice and 190 to 1 for wheat. Brennan et al. (1997) estimated that 64 percent of the genetic improvements to Australian rice came from international germplasm, and that the total Australian benefits of varietal yield improvement from 1962 to 1994 were $848 million (1994).

Evenson and Gollin (1997) estimated that without the International Network for the Genetic Evaluation of Rice, 20 improved varieties of rice would not have been released. The present value of that lost production over a 20-year period (the average length of time a rice variety is economically viable) was estimated to be $1.9 billion. Using a discount rate of 10 percent, the authors estimated that the present value of an added landrace (in a variety introduced by the program) was $50 million.

[1]Technically, Thirtle estimated the rate of land-saving biological-chemical technical change as an exponential time trend within a nested Cobb-Douglas/CES production function. In the same function, a different exponential time trend was used to estimate labor-saving mechanical technological change.

contributions of conserving genetic resources in farmers' fields or in gene banks. Nor do most studies provide a detailed welfare analysis of costs and benefits across producers (including non-adopters) and consumers.

Frisvold et al. (2003) attempted to overcome some of the limitations of earlier studies by adding two features: a global welfare analysis, and a multimarket partial equilibrium model that could calculate the joint effects of genetic improvements in five major crops in the United States between 1975 and 1992.[4] They first estimated the size and distribution of the gross annual benefits of a single-year increase (fig. 2, first panel) in the U.S. yields of corn, soybeans, wheat, cotton, and sorghum. About half of the increase in yields can be attributed to improved seed varieties (Fuglie et al, 1996).[5] Accordingly, to simulate the effects of genetic improvement only, the authors increased the supply of crops by half of the average annual yield growth, implicitly assuming no changes in other inputs and no interactions between genetic improvements and other inputs.

Frisvold et al. estimated that the overall economic welfare of U.S. crop producers across the five commodities increased by more than $160 million and that consumer welfare increased by more than $220 million (1989 constant dollars) due to U.S. genetic improvements. Total U.S. economic welfare increased over $350 million. Producers in the rest of the world suffered losses, while consumers in the rest of the world gained from lower world food prices. Net global welfare increased by $590 million, with the United States capturing 60 percent of the total gain, other developed countries 25 percent, and developing and transitional economies 16 percent.

In fact, yield increases from genetic improvements are not limited to a single year, so Frisvold et al. also calculated the present value of a permanent increase in yields from genetic improvements (fig. 2, second panel).[6] The U.S. benefits of permanent U.S. yield increases range from just under $5 billion (1997 dollars) to over $9 billion. Global benefits range from $8 billion to $15 billion and benefits to developing and transitional economies range from $1 billion to $2.5 billion. (Consumer benefits in developing and transitional economies range from $6 billion to over $11 billion.)

These estimates are conservative for two reasons. First, growth in income and population over time would make the total benefits of yield increases even larger as demand grows. And second, "plant breeding and genetic improvements have not merely generated one-time permanent increases in yields, but rather an annual stream of permanent yield improvements. Every year there is a new incremental permanent increase in yields. The problem is equivalent to receiving a new annuity of varying value every year" (Frisvold et al., 2003) (fig. 2, third panel).[7]

These results suggest that investment in genetic enhancement has generated large returns. The United States was the major beneficiary of genetic enhancement in U.S. crops, although the genetic resources used in these improvements might have multiple sources. (Note that Frisvold et al.'s analysis did not include the U.S. research costs necessary to achieve these yield gains.) Nonetheless, developing and transitional economies also benefited from U.S. yield gains, and it is likely that poor consumers in these countries (including many small farmers) are among the major beneficiaries.

[4] Most studies have focused only on genetic improvements for a single crop.

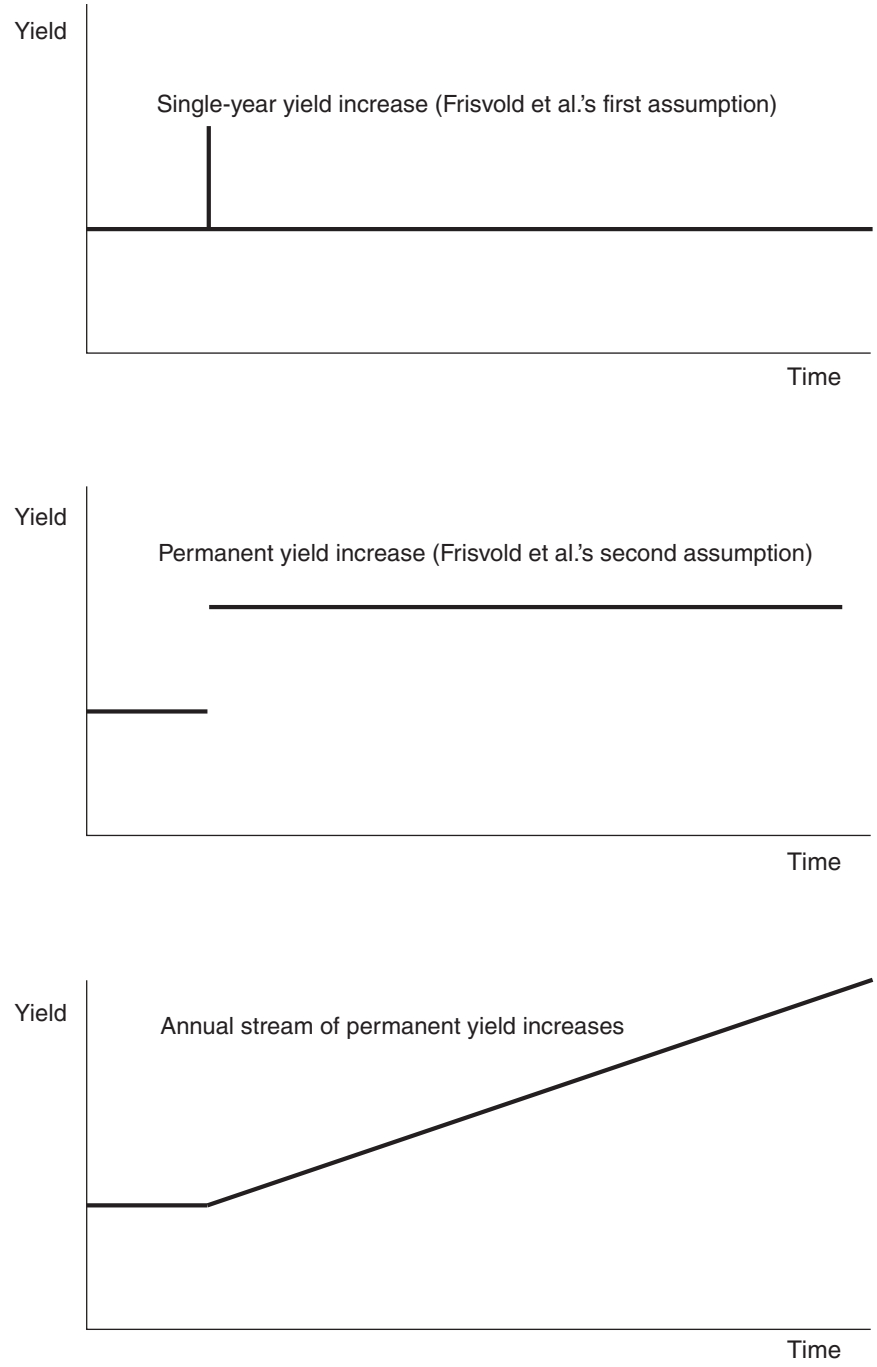
[5] The average annual growth in U.S. crop yields during 1975–92 was 1.33 percent for corn, 1.54 percent for sorghum, 1.13 percent for wheat, 1.23 percent for soybeans, and 2.23 percent for cotton. The half of the yield growth not attributed to improved seed varieties came from other inputs and management factors, including more fertilizers and pesticides, better agronomic practices, and investments in irrigation and drainage. These other sources of productivity growth also may have been affected by agricultural research.

[6] In other words, annual yield gains attained in a given year are maintained in the years following.

[7] Of course in the long term, research gains may be counteracted by losses of resistance to pests and diseases, but in a successful research program the net gains are positive. The point here is that it is more realistic to look at research gains as a permanent stream over time rather than as an economic benefit occurring only once. If investments are ongoing, new additions to the permanent stream are received every year. Furthermore, avoidance of losses is in fact an economic benefit as well.

Figure 2

Alternative assumptions about benefits from genetic enhancement



Searching for Valuable Genetic Resources

Genetic enhancement depends on the availability of diverse genetic resources for use by plant breeders. In addition to evaluating genetic enhancement, economists have also attempted to evaluate the search for agricultural genetic resources *in situ* (in their natural habitat), the storage and characterization of these resources *ex situ* (e.g. in germplasm collections), and the search for particular traits within *ex situ* collections. Compared with estimates of returns to genetic enhancement, estimates of search costs and returns often are more complex conceptually and more demanding of scarce data (see box, "Economic Models of Searching for Genetic Resources").

Most models of the economics of searching for genetic resources held *in situ* or *ex situ* have been difficult to apply empirically due to data limitations. Several different types of empirical studies have, however, provided useful information about the economics of conservation. First, Evenson and Gollin (1997) directly estimated likely benefits of additional accessions to the rice collection maintained by the International Network for the Genetic Evaluation of Rice. They estimated that the present value of 1,000 additional accessions (discounted at 10 percent over a 20-year period) was $325 million.

Second, Pardey et al. (2001; 2004) estimated the marginal costs of adding accessions to the *ex situ* gene bank for wheat and maize (corn) at CIMMYT, the International Maize and Wheat Improvement Center, and estimated the cost of holding an additional accession in perpetuity. Though Pardey et al. did not estimate the expected values of benefits for additional accessions (and suggested it might not even be feasible), they argued that the cost of additional wheat accessions was so low that expected benefits would probably always outweigh this cost. They argued that some accessions to the maize gene bank—e.g., landraces and wild relatives—might be more likely to have an expected positive return than others, like recently created breeding lines. This is because useful genetic material contained in breeding lines might well be conserved elsewhere—for example, by maize breeding programs—but useful genetic material in landraces and wild relatives would probably be conserved only in the gene bank.[8]

Third, surveys of plant breeders and other users of gene banks have consistently showed that they find gene bank materials useful. For example, the U.S. National Plant Germplasm System (NPGS) is one of the largest national gene banks in the world; it distributes, for free, more germplasm samples internationally than any other supplier, including the international research centers of the CGIAR. Smale and Day-Rubenstein (2002) found that international users of the NPGS requested materials for a variety of uses, including basic research and breeding, and a majority expected that their use of NPGS materials would stay the same or increase in the future. Of NPGS samples distributed from 1995 through 1999, 11 percent had been used in breeding programs, 18 percent were found useful in other ways, and 43 percent were still being evaluated. Twenty-eight percent of the samples were not considered useful. Rejesus et al. (1996) found that wheat breeders around the world used released cultivars, advanced materials, and germplasm from international nurseries much more frequently than wild relatives and landraces. Wild relatives and landraces were used particularly in search of specific traits, such as disease resistance, drought resistance, and quality.

[8] Koo et al. present additional cost figures for CGIAR gene banks. For many cost compoinents of gene bank operation, cost estimates fall between the estimates for wheat and maize.

Economic Models of Searching for Genetic Resources

Simpson, Sedjo, and Reid (1996) applied a theoretical model, originally used in labor economics, to biodiversity conservation in the context of a search for species of interest to pharmaceutical research. Modifying this model, Simpson and Sedjo (1998) argued that the value to society of biodiversity prospecting (searching for genetic resources currently held *in situ*) for use in crop improvement programs was likely to be low.

Cooper (1998) approached the question as one of investment in "converting" *in situ* genetic resources into *ex situ* resources under (1) uncertainty concerning the measurement and value of *in situ* genetic resources, and (2) irreversibility since *in situ* resources, once lost, cannot be replaced. Cooper's simulations demonstrated that estimates of mean benefits might not be particularly useful, as the range of potential benefits could be quite large.

Evenson and Lemarié (1998) applied a search model to a two-stage process—first, collecting genetic resources *in situ* and placing them *ex situ*, and second, searching the *ex situ* collection for traits of interest. They showed that the optimal size of a collection depends on the number of traits being sought, and on the distribution of genetic resources across geographic regions.

Gollin, Smale, and Skovmand (2000) developed a theoretical model that characterizes the search for resistance to pests and diseases in *ex situ* collections of wheat genetic resources, and then analyzed data on frequency distributions, disease losses, and search costs. They concluded that "the optimal size of search for traits is highly sensitive to the economic magnitude of the problem, the research time lag, and the probability distribution of the trait." Furthermore, even though subcollections of landraces or wild relatives might be used only on rare occasions, high benefits might result on those occasions. The fact that "gene banks and some categories of accessions"—i.e., certain types of genetic materials held by a gene bank—"are infrequently demanded by crop breeders does not in itself imply that marginal accessions have low value."

Drawing on these earlier studies, Rausser and Small (2000) argued that scientific models that "channel research effort towards leads for which the expected productivity of discoveries is highest" significantly reduce search costs from earlier "brute force" models that assume no prior information can be brought to the search. In contrast to the results of Simpson et al., Rausser and Small's simulations suggest that market-based conservation of genetic resources might be possible in some cases because prior information reduces private search costs so they are lower than expected private benefits from searching.

One final consideration refers not to the economics of plant genetic resource conservation *per se,* but to a related scientific development bearing on economic decisionmaking. This is the potential of modern molecular biology, including genomics, to reduce the search costs for useful traits in conserved material. (Genomics refers to investigations into the structure and function of very large numbers of genes undertaken simultaneously.) At this point, however, it is relatively easy to generate mountains of raw genetic sequence data but difficult to transform these data into useful information (Attwood, 2000). Thus, conserved genetic resources may increase in value as genomics and other molecular techniques lower search costs and the costs of capitalizing on search results, but it is difficult to predict the pace at which this will take place.

The literature on searching for valuable genetic resources is less conclusive than the literature on evaluating the benefits of genetic enhancement. The majority of studies agree that economic benefits from searching for genetic resources either *in situ* or *ex situ* are positive compared with costs. This can be true even if successful searches are a small fraction of the total searches conducted. However, studies also conclude that it is quite difficult to value searches for genetic resources, and that the range of potential values may be large. The key variable is information. Application of prior information about the probability distribution of a desired trait or set of traits and where searches are likely to have the highest payoffs can significantly increase the economic value of a search for genetic resources. This prior information might be embodied in knowledgeable individuals, scientific publications, characterization of gene bank holdings, or the findings of molecular biology.

Taken together, economic analysis of genetic enhancement and the search for genetic resources indicate that returns to the discovery and use of crop genetic resources exceed the costs. Many scientists, however, have raised concerns about the continued availability of sufficient genetic resources for future plant breeding efforts. Furthermore, both the scientific and economic literatures agree that the measurement of genetic diversity is complex.